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Investigation of Non-Lubricated Piston Ring Problems - Cause, Effect and Solution

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INVESTIGATION OF NON-LUBRICATED PISTON RING PROBLEMS - CAUSE, EFFECT AND SOLUTION

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SYNOPSIS

Many ring problems in petrochemical and process gas industries that have occurred over the last decade on reciprocating non-lubricated compressors are examined.

The causes, effects and solutions are correlated by analysis of the methods by which the problems were overcome in applied situations, a few of which are examined in depth for illustrative purposes.

Conclusions are drawn as to good current practice for the achievement of reliable piston ring operation in non-lubricated reciprocating process gas compressors.

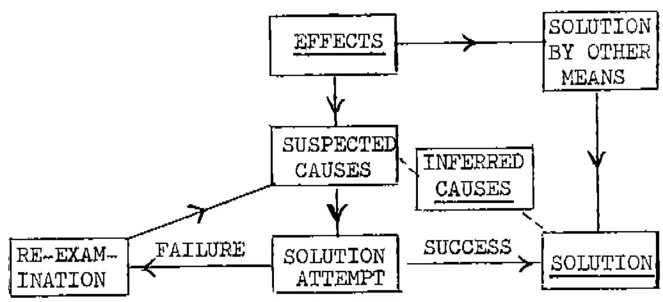
INTRODUCTION

In process gas and petrochemical industries reliable oil-free compressors are vital, because of the extremely high downtime costs. The majority of the oil-free compressors used in these industries are of the horizontal reciprocating type and are generally found to be very reliable, the pistons being fitted with compression and bearer rings made from PTFE filled with various inorganic fillers such as carbon, glass fibre, and molybdenum disulphide, or combinations of these. In addition there exist composite materials consisting of PTFE, carbon, molybdenum disulphide, compounded with epoxy binders, as well as alternative filled plastics such as polyimides and polyphenylene sulphides. The compression rings are normally self actuating and act as sealing elements between the piston and the cylinder. The bearer rings support the weight of the piston and act so as to prevent the piston contacting the cylinder wall.

It is found that the rings initially will wear by up to 0.010" (0.25 mm) and in so doing will transfer a film to the cylinder wall. After the transfer film has been produced the wear rate of the rings is correspondingly reduced to lower levels. The mechanism of this film transfer is not completely understood and there are various mechanisms propounded by Arkles, ref. 1, Richardson ref. 2, and Evans ref. 3. However, it appears to be essential to produce such a film if reliable ring performance is to be obtained, and in fact in all the cases examined, unsatisfactory ring life was concurrent with absence of a visible transfer film. It is hoped that by an examination of what not to do, a greater understanding can be obtained of how reliability can be improved still further.

RESULTS

Figure 1 shows a collection of data from 20 problem cases. These cases refer to a selection of problems encountered by the author over the last decade. Causes, effects and solutions to the problems were obtained by the methodology illustrated below.



The effects and solutions were obtained directly from actual field observation. The causes were derived by relating solution of the problem and suspected causes. This is best illustrated by considering one of the cases in greater depth.

Case 8

These machines are single stage horizontal, boosting the pressure of bone dry hydrogen gas from 200 p.s.i. (14.1 kg.cm2) to 600 p.s.i. (42.2 kg.cm2). Monolithic butt-jointed bearer rings and monolithic self actuating butt-jointed compression rings were used, fabricated in a carbo-graphite filled PTFE material. Initially a variable bearer ring life of between 200 and 2,000 hours was achieved; also there was a loss of gas throughput within a short period of fitting new rings. Examination of the worn rings revealed that the bearer rings had extruded (i.e. parts of the ring had flowed under the influence of pressure and temperature); also the compression rings were found to have relaxed so that they were no longer in contact with the cylinder wall. Gas delivery temperature records indicated that from time to time temperatures of up to 392°F (200°C) were being encountered during operation of the compressors.

The solutions to the problems were

(1) By replacement of the ring material with an epoxy bonded composite material better able to cope with a bone dry gas and with higher temperatures (ref. 4 and 5).

(2) By thoroughly cleaning the water passages of the cylinder cooling and implementing a regular maintenance program. This was done as an attempt to overcome a high temperature condition considered to be caused by a combination of inadequate maintenance and inadequate design of the cylinder cooling system.

(3) Modification was made to the compression rings using a twin ring design in which a self actuating butt-jointed inner ring was used with its gap at 180 degrees to the gap of a self actuating outer ring. This design was used so as to minimise leakage of the low molecular weight hydrogen gas past the compression rings and thereby reduce any loss of gas throughput.

As a result of the above solutions, bearer ring life was consistently increased to a figure in excess of 15,000 hours, excessive gas temperatures were not recorded, and there was no measurable loss of gas throughput.

In summary, effects and solutions are

Effects

(1) High ring wear.

(2) High temperature, giving secondary effects such as ring extrusion.

(3) Lowering of gas throughput.

Solutions

(1) Use of compressor correctly (i.e. implementation of a regular maintenance program for cleaning cylinder water passages).

(2) Alter the compression ring design so as to improve sealing.

(3) Alter the ring material so as to combat the bone dry nature of the gas and the high temperatures encountered.

Causes were derived by relating the solutions with the reasons behind the changes made to obtain the solutions. In this case, causes were derived as:-

(1) Incorrect use of the compressor.

(2) Incorrect selection of ring material and/or design.

By a similar methodology (except for cases 4 and 19) causes, effects and solutions were obtained for all twenty cases. (Figure 2). It should be noted that for cases 4 and 19, solution was by other means, i.e. the compressors were converted to lubricated duties to overcome the problems.

Discussion of Results

Figure 2 shows that causes, effects and solutions were able to be categorised as follows. (A few illustrative causes are given in figure 3.)

Causes : A. Upstream system (i.e. the system prior to the compressor).

B. Use of the compressor.

C. Selection of ring materials and/or design of rings.

Effects: 1. High ring wear.

2. High temperature giving secondary effects such as ring extrusion.

3. Ring breakage.

4. Loss of compressor efficiency.

Solutions: a. Exclude extraneous matter.

b. Remove ovality of compressor cylinders.

c. Use compressor correctly.

d. Alter ring design.

e. Alter ring material.

f. No action.

Solution by other means

α Lubricate machine with an oil compatible with the process.

The range of causes of the problems is shown in figure 3. It is interesting to note that even though high ring wear occurs in all cases except one, in only approx. 50% of cases does changing the ring material solve the problem.

The results obtained are not analysed to too great a depth because the nature of the selection of cases is not random and therefore not necessarily representative of ALL problems. However, it is felt that certain conclusions can be made as to good current practice so as to achieve reliable compressor operation.

Conclusions as to good current practice.

(1) Greater consideration be made as to provision of better filtration of gas prior to entry

into a non-lubricated compressor.

(2) The user of a new compressor record all wear-down data until such time that a predictable ring life is achieved. This not only helps the user to optimise ring performance but also helps the 'troubleshooter' in case a problem develops.

(3) Care be taken by the user of the machine that the compressor manufacturer's operating instructions are observed.

(4) Careful selection of ring material and/or ring design be made by the compressor manufacturer.

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Case	Gas	Final Discharge Pressure		Final Discharge Temperature		No. of. Stages	Configuration	Mean Piston Speed	
		(psi)	(kg/cm^2)	(^oF)	(^oC)			(Ft/min)	(M/sec)
1	Argon	150	(10.5)	255	(124)	2	Horizontal	570	(2.9)
2	Oxygen	630	(44.3)	248	(120)	4	Horizontal	647	(3.3)
3	Oxygen	600	(42.2)	351	(177)	1	Vertical	388	(2.0)
4	Propylene*	279	(19.6)	189	(87)	2	Horizontal	728	(3.7)
5	Nitrogen	2250	(158.1)	289	(143)	5	Horizontal	735	(3.7)
6	Nitrogen	440	(30.9)	268	(131)	2	Horizontal	722	(3.7)
7	Air	383	(26.9)	338	(170)	2	Horizontal	667	(3.4)
8	Hydrogen	600	(42.2)	392	(200)	1	Horizontal	287	(1.5)
9	Hydrogen*	400	(28.1)	165	(74)	1	Horizontal	500	(2.5)
10	Hydrogen*	375	(26.4)	320	(160)	1	Horizontal	500	(2.5)
11	Propylene	233	(16.4)	154	(68)	2	Horizontal	722	(3.7)
12	Ethylene	1500	(105.4)	208	(98)	1	Horizontal	644	(3.3)
13	Helium	252	(17.7)	268	(131)	4	Horizontal	700	(3.6)
14	Methane	150	(10.5)	284	(140)	2	Horizontal	720	(3.7)
15	Hydrogen	215	(15.1)	354	(179)	2	Horizontal	613	(3.1)
16	Air	150	(10.5)	330	(166)	2	Horizontal	720	(3.7)
17	Carbon Dioxide	130	(9.1)	181	(83)	3	Vertical	390	(2.0)
18	Nitrogen	150	(10.5)	230	(110)	2	Vee	620	(3.2)
19	Carbon Monoxide	395	(27.8)	313	(156)	2	Horizontal	792	(4.0)
20	Methane	141	(9.9)	252	(122)	3	Horizontal	800	(4.1)

* Gas stated is major constituent.

FIGURE 1

Case	Initial Ring Life (Hrs.)	Estimated and/or Ultimate Ring Life (Hrs.)	Inferred Cause	Effect	Solution	Solution by other means
1	2000	45000	C	1	e	
2	350	15000+	C	1	e	
3	2000/20000	20000	C	3	d,e	
4	200	3000	A	1		α
5	170	75000	C	1	e	
6	500*	9000+	A	1	a	
7	500	8000+	A	1	a	
8	200	15000	B,C	1,2,4	c,d,e	
9	1000	6000+	A	1	a,b	
10	1500	6000+	B	1,2	f	
11	350*	8000	A	1	a	
12	500	8000	B	1,2,4	c	
13	1200*	3000+	A,C	1,4	a,d	
14	2500	15000	C	1	e	
15	3000	8000+	B	1,2	f	
16	2000	6000+	A,C	1	a,d,e	
17	500	8000	C	1	e	
18	100	8000+	C	1	e	
19	200	2000	A,B,C	1		α
20	1000	8000+	C	1	e	

* Applies to first stage only.

Cause

A. Upstream system.

B. Incorrect use of compressor.

C. Incorrect selection of ring material and/or ring design.

Effect

1. High ring wear.
2. High temperature.
3. Ring breakage.
4. Lack of sealing efficiency.

Solution

a. Exclude extraneous matter.

b. Remove cylinder ovality.

c. Use compressor correctly.

d. Alter ring design.

e. Alter ring material.

f. No action.

Solution by other means

α Lubrication.

FIGURE 2

A Few Illustrative Causes

A. Upstream System	B. Use of Compressor	C. Selection of Ring Material and/or Design
Ingression into compressor of rust, concrete, and welding debris. Partial polymerisation of gas.	Gas temperature too high. Lack of maintenance of cylinder cooling. Dynamiting in the vicinity of the compressor.	Incorrect ring design. Incorrect ring material selection in relation to the dryness of the gas (Ref. 4, 5) and incorrect material selection in relation to the gas temperature. Incorrect material selection in relation to the nature of the gas.

FIGURE 3